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Managerial Incentives, Innovation and Product Market Competition

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Abstract

This paper investigates the strategic value of the managerial incentive scheme in affecting firms' incentive in R&D investment and their product market activities. Firstly, we find that in Cournot-quantity competition, owners strategically assign a non-profit-maximization objective to their managers. Consequently, managers in a delegation game invest more in cost-reducing R&D, and have higher output, lower prices and lower profits, as compared to profit-maximizers in a owner-run game. Secondly, we find that R&D collusion induces owners in a delegation game to choose more aggressive managerial incentives as compared to R&D competition, which in turn leads to increased R&D investment, reduced product prices and increased profits.

Key Words: Strategic Delegation, Managerial Incentives, R&D competition and R&D collusion.

JEL Classification: C72, D20, L22, O32

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1. Introduction

Empirical and theoretical research has yielded numerous insights into the intricate relationship between technological innovation and market structure in a given industry. However, the role of managerial incentives in this context has received relatively little but growing attention in the literature. What kind of managerial incentive scheme is more conducive to technological advancement and economic growth? How does product market competition affect the designing of managerial contracts and the incentive for technological innovation? Do different forms of technological innovation require different types of managerial incentives and how does this affect market outcomes? This paper attempts to address these questions.

The strategic value of a managerial contract in enhancing a firm's competitiveness has been investigated in the strategic delegation literature. For instance, Vickers (1985), Fershtman (1985), Fershtman and Judd (1987) and Sklivas (1987) have demonstrated that, in an oligopolistic industry, the owner of a firm may strategically design non-profit-maximizing managerial incentives for the manager. With Cournot-quantity competition, for instance, they have shown that a sales-promoting incentive contract may be more profitable to the owner than a profit-maximizing one.

This early work, however, neglects the strategic interconnections of managerial contracts with firms' incentives to innovate and in turn its market implications. The objective of this paper is to investigate the strategic interactions between firms, in both R&D activities and market place, on the owner's choice of managerial contracts. It also investigates the role of collusive R&D activities in influencing the design of managerial incentive scheme. We want to stress that the managerial incentives could be used by an

owner as a strategic device to manipulate its rival manager's behavior, not only in product market but also in R&D activities. On the other hand, managers' different forms of R&D activities such as R&D collusion and R&D competition require different optimal managerial incentives and induce different market outcomes.

In this paper, we consider a duopolistic industry in which each firm has one owner and one manager. Owners design incentive schemes for the managers, while managers make R&D and production decisions sequentially. The owners' objective is to maximize firm profits while the managers' is to maximize compensation. The owner delegates the game to manager to play on owner's behalf. The managerial contract serves as a precommitment for an owner to manipulate the actions of the rival manager in both R&D and production activities. We extend the managerial incentive framework introduced by Fershtman and Judd (1987) and Sklivas (1987) (hereafter, FJS) by endogenizing production cost in the R&D stage. The cost-reducing R&D is modeled according to Kamien, Muller and Zang (1992) (hereafter, KMZ).

In particular, we analyze a three-stage game. In the first stage, owners simultaneously design a managerial incentive scheme which is publicly observable.¹ Following FJS, the incentive scheme is some linear function of firm profits and revenues. This function is endogenously chosen by an owner as a strategic tool to commit its manager to certain actions in the future R&D and product stages. Given the incentive scheme, in the second stage, managers make R&D decisions. In the third stage, managers make production decisions under Cournot-quantity competition.

¹ Katz (1991) demonstrates that public observability of the managerial contracts is crucial in obtaining the strategic effects discussed in the strategic delegation literature.

It is shown that at equilibrium, each owner directs its manager away from profit-maximization to include sales. As a consequence, managers in the delegation game behave more aggressively in both the R&D stage and production stage as compared to the profit-maximizers in owner-run game. That is, they have higher R&D investment, higher output, lower price and lower profits than the profit-maximizers. In addition, it is shown that cooperative R&D induces owners to design more aggressive managerial incentives than non-cooperative R&D. As a result, R&D collusion brings about higher R&D investment, lower prices but higher profits as compared to R&D competition.

Our first result is similar to that of FJS. Consider both downward-sloping R&D reaction functions and output reaction functions. By strategically designing a sales-promoting incentive scheme, an owner enhances the aggressiveness of the manager when interacting with the rival (named “top dog” behavior by Tirole (1988)). This shifts out the firm’s R&D reaction function as well as output reaction function, which implies higher R&D investment, higher market share and higher profits. The owner, in fact, acts as a Stackelberg leader of the manager of the rival firm. Naturally, when both owners design aggressive incentive schemes for their managers, the prisoners’ dilemma implies lower profits for both firms in the symmetric equilibrium.

Our second result, however, is in sharp contrast to standard outcomes in the cooperative R&D literature. According to, for instance, d’Aspremont and Jacquemin (1988) and Kamien, Muller and Zang (1992), in the absence of R&D spillovers, cooperative R&D leads to lower R&D investment and higher product prices as compared to non-cooperative R&D. This is no longer true once owners choose managerial incentives prior to managers’ R&D and production decisions. The intuition is as follows: R&D collusion raises profitability in product market, which drives owners to design more aggressive managerial

incentives. This in turn leads to increased R&D activities as compared to non-cooperative R&D, and product prices drop as a result of enhanced firm competition.

The rest of this paper is organized as follows. In the next section, we set up a model for strategic delegation with R&D. Section 3.1 analyzes the managerial incentives under non-cooperative behaviors in both the R&D and production stages. Section 3.2 examines managerial incentives and market implications under cooperative R&D. Section 4 compares the delegation game under non-cooperative R&D with that under R&D collusion. The final section summarizes the results.

2. A Model of Strategic Delegation with R&D

In this section we develop a model embodying managerial incentives, R&D activities, and product market competition. There are two firms (i and j) run by one manager each, playing a three-stage game. In the first stage, owners simultaneously sign an incentive scheme with their managers. In the second stage, managers either compete or collude in R&D activities. In the third stage, managers compete in product market according to Cournot. Following FJS, managers are characterized by a managerial incentive parameter $\alpha_i > 0$, where α_i is the weight on profits in manager i's objective function given by $U_i = \alpha_i \pi_i + (1 - \alpha_i) R_i$, where π_i and R_i are firm i's profit and revenue functions, respectively. A profit-maximizing firm is then analogous to setting $\alpha_i = 1$. In general, by varying α_i , different levels of aggressiveness by the managers can be analyzed. In particular, letting $\alpha_i < 1$ implies that managers put a higher weight on revenue, or equivalently a lower weight on

costs.² In this sense, managers in the delegation game behave more aggressively than profit-maximizers.

In stage 1, owner i maximizes profits by choosing the incentive parameter α_i . In doing so, owner i uses the incentive scheme U_i as a strategic device to commit manager i to certain actions in the following R&D and production stages.

In Stage 2, given the incentive scheme, manager i decides on cost-reducing R&D investments x_i to maximize U_i . The marginal costs of firm i are given by $C_i = c - f(x_i)$, where $f(x_i)$ is the R&D production function, i.e., the amount of reduction in i 's marginal costs resulting from i 's R&D input x_i . There are no R&D spillovers. Following KMZ, it is assumed that $f(x_i)$ is twice differentiable, increasing ($f' > 0$), concave ($f'' < 0$), $f(0) = 0$, and uniformly bounded. There are no fixed costs.

In Stage 3, given the incentive scheme and R&D decisions, manager i chooses production quantity q_i to maximize U_i according to Cournot. As an extension of the previous literature, we use a general demand function $p(Q)$, assuming $p' < 0$ and $p'' > 0$ (where $Q = q_i + q_j$ is the sum of firm i and j 's output)

3. Managerial Incentives, R&D and Market Competition

3.1. Managerial Incentives under Non-Cooperative Behavior

In this section we solve the above game for a subgame perfect equilibrium assuming that firms behave non-cooperatively in both R&D investment as well as in the product market.

² Note that the manager's objective function can be written as $U_i = R_i - \alpha_i TC_i$.

For simplicity we only analyze symmetric equilibrium. In Stage 3, manager i chooses q_i to maximize U_i yielding the first-order conditions (we denote derivatives by superscripts),

$$U_i^{q_i} = p'q_i + p - \alpha_i(c - f(x_i)) = 0. \quad (1)$$

From equation (1), it is clear that manager i acts as if the marginal production cost is $\alpha_i(c - f(x_i))$, instead of $(c - f(x_i))$. The existence and the stability of Stage 3 equilibrium are guaranteed by the following assumption:³

Assumption 1: $p''q_i + p' < 0$.

This assumption assures that both output reaction curves are downward-sloping, i.e., managers compete in quantities which are strategic substitutes.

The following Lemma describes the impact of R&D on final stage equilibrium output decisions.

Lemma 1: An increase in firm i 's R&D investment increases firm i 's equilibrium output but decreases the rival firm's equilibrium output. That is, $\frac{dq_i}{dx_i} > 0$; $\frac{dq_j}{dx_i} < 0$.

Proof: Implicit differentiation of equation (1) w.r.t. x_i yields,

$$\frac{dq_i}{dx_i} = -\frac{\alpha_i f_i' U_j^{q_j q_i}}{\eta^q} > 0 \quad \text{and} \quad \frac{dq_j}{dx_i} = \frac{\alpha_i f_i' U_j^{q_j q_i}}{\eta^q} < 0. \quad \text{Q.E.D.}$$

Lemma 1 is rather intuitive. More R&D spending by firm i increases its output since it reduces its marginal production cost. This in turn decreases j 's output through

³ This assumption assures that the second-order conditions $\eta^q = U_i^{q_i q_i} U_j^{q_j q_j} - U_i^{q_i q_j} U_j^{q_j q_i} > 0$, $U_i^{q_i q_i} < 0$ and $U_i^{q_i q_j} < 0$ are satisfied for any symmetric equilibrium, where $U_i^{q_i q_i} = p''q_i + 2p'$ and $U_i^{q_i q_j} = p''q_i + p'$.

strengthening i 's competitiveness due to the competition effect. Note that the industry aggregate output always increases as one of the firms increases its cost-reducing R&D.⁴

Next, we examine the (partial) effects of managerial incentives on output decisions, on the condition that both firms' R&D investments are fixed. Implicitly differentiating equation (1) w.r.t. α_i , we have

$$\frac{\partial q_i}{\partial \alpha_i} = \frac{(c - f_i)U_j^{q_j q_j}}{\eta^q} < 0 \quad \text{and} \quad \frac{\partial q_j}{\partial \alpha_i} = -\frac{(c - f_i)U_j^{q_j q_i}}{\eta^q} > 0. \quad (2)$$

Hence, as owner i lowers α_i , firm i 's output increases but firm j 's output decreases, provided that both firms' R&D investment remains unchanged.

However, as α_i changes, both firms' R&D investments also change. The (total) effects of a change in α_i on production consist of two parts:⁵ first, the partial effects, as shown in the above; second, the R&D effects. These are the effects of α_i on output through changing both firms' R&D investment, which are discussed next.

In Stage 2, manager i chooses the R&D level x_i to maximize U_i yielding the first-order conditions,

$$U_i^{x_i} = q_i \left(p' \frac{dq_j}{dx_i} + \alpha_i f_i' \right) - \alpha_i = 0. \quad (3)$$

⁴ It is straight-forward that $\frac{d(q_i + q_j)}{dx_i} = -\frac{\alpha_i f_i' (U_j^{q_j q_j} - U_j^{q_j q_i})}{\eta^q} > 0$.

⁵ The total effects of α_i on outputs are

$$\frac{dq_i}{d\alpha_i} = \frac{\partial q_i}{\partial \alpha_i} + \left(\frac{dq_i}{dx_i} \frac{dx_i}{d\alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right); \quad \frac{dq_j}{d\alpha_i} = \frac{\partial q_j}{\partial \alpha_i} + \left(\frac{dq_j}{dx_i} \frac{dx_i}{d\alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right).$$

The first term, $q_i(p' \frac{dq_j}{dx_i} + \alpha_i f_i')$, represents the positive effect of manager i's R&D effort on its utility through changing the rival's output and its own marginal cost as well. The second term, α_i , is the marginal R&D cost.

The existence and stability of equilibrium in the R&D stage are guaranteed by the following assumption.

*Assumption 2: The second order conditions satisfy that $\underline{U_i^{x_i x_i} < 0}$, $\underline{U_j^{x_j x_j} < 0}$ and $\eta^x = U_i^{x_i x_i} U_j^{x_j x_j} - U_i^{x_i x_j} U_j^{x_j x_i} > 0$.*⁶

This assumption is simplified into Assumption 2 in Kamien, Muller and Zang (1992) for a linear demand function. It assures that x_i and x_j are strategic substitutes, i.e., both firms' R&D reaction curves are downward-sloping.

The effects of managerial incentives on R&D decisions are given by the following Lemma.

Lemma 2: As owner i lowers α_i , firm i's R&D investment increases but firm j's R&D investment decreases. That is, $\frac{dx_i}{d\alpha_i} < 0$; $\frac{dx_j}{d\alpha_i} > 0$.

Proof: See Appendix.

The intuition is as follows. As owner i lowers α_i , firm i's R&D reaction curve shifts out but firm j's R&D reaction function shifts in. This increases i's R&D investment but

⁶Where $U_i^{x_i x_i} = -U_i^{q_i q_i} (\frac{dq_i}{dx_i})^2 + p'' q_i (\frac{dq_j}{dx_i})^2 + p' q_i \frac{d^2 q_j}{dx_i^2} + \alpha_i f_i'' q_i$;

$U_i^{x_i x_j} = -U_i^{q_i q_j} \frac{dq_i}{dx_i} \frac{dq_j}{dx_j} + p'' q_i \frac{dq_j}{dx_i} \frac{dq_j}{dx_j} + p' q_i \frac{d^2 q_j}{dx_i dx_j}$.

decreases j 's R&D investment. Note that as one of the owners lowers α_i , the total R&D expenditure always increases.⁷

Now let us examine the (total) effects of managerial incentives on final stage equilibrium output, which is given by Lemma 3.

Lemma 3: As owner i lowers α_i , firm i 's equilibrium output increases but firm j 's decreases. That is, $\frac{dq_i}{d\alpha_i} < 0$; $\frac{dq_j}{d\alpha_i} > 0$.

Proof: The proof is trivial from equation (2), Lemma 1, 2 and the following equations,

$$\frac{dq_i}{d\alpha_i} = \frac{\partial q_i}{\partial \alpha_i} + \left(\frac{dq_i}{dx_i} \frac{dx_i}{d\alpha_i} + \frac{dq_i}{dx_j} \frac{dx_j}{d\alpha_i} \right); \quad \frac{dq_j}{d\alpha_i} = \frac{\partial q_j}{\partial \alpha_i} + \left(\frac{dq_j}{dx_i} \frac{dx_i}{d\alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right). \quad \text{Q.E.D.}$$

Therefore, the effects of managerial incentives on market shares are unambiguous. As owner i lowers α_i , firm i 's market share increases while the rival firm j 's declines. This is because manager i acts as the marginal production cost is $\alpha_i(c - f(x_i))$, instead of $(c - f(x_i))$. As owner i reduces α_i , firm i 's output reaction curve shifts out but firm j 's output reaction curve shifts in since $\frac{d(\alpha_i(c - f(x_i)))}{d\alpha_i} = (c - f_i) - \alpha_i f'_i \frac{dx_i}{d\alpha_i} > 0$ and

$$\frac{d(\alpha_j(c - f(x_j)))}{d\alpha_i} = -\alpha_j f'_j \frac{dx_j}{d\alpha_i} < 0. \text{ Note that the total market output always increases as}$$

one of the owners lowers α_i . That is, $\frac{d(q_i + q_j)}{d\alpha_i} < 0$.

In an FJS setting, the change in one owner's managerial incentive parameter only shifts its own output reaction function but not the rival firm's. However, when production cost

⁷ It is shown in Appendix that $\frac{d(x_i + x_j)}{d\alpha_i} < 0$

is endogenized in the R&D stage as in this paper, any change in one owner's managerial incentive parameter will change both firms' R&D investment, and consequently their marginal production costs. This causes both firms' output reaction curves to shift, although in opposite directions. Therefore, when firms compete not only in market place but also in R&D activities, the strategic effects of managerial incentives upon managers' productions are magnified through the effects on managers' R&D investment.

In Stage 1, owner i chooses α_i to maximize π_i yielding the first-order conditions,

$$\pi_i^{\alpha_i} = -(1 - \alpha_i)(c - f_i) \frac{dq_i}{d\alpha_i} - (1 - \alpha_i)(1 - f_i'q_i) \frac{dx_i}{d\alpha_i} + p'q_i \left(\frac{\partial q_j}{\partial \alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right). \quad (4)$$

Rearranging it, we have ⁸

$$1 - \alpha_i = \frac{p'q_i \left(\frac{\partial q_j}{\partial \alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right)}{(c - f_i) \frac{dq_i}{d\alpha_i} + (1 - f_i'q_i) \frac{dx_i}{d\alpha_i}} > 0. \quad (5)$$

We can characterize the symmetric subgame-perfect equilibrium ($\alpha_i = \alpha_j \equiv \alpha_N$) by the following theorem.

Theorem 1: There exists a unique symmetric equilibrium such that $\alpha_N < 1$.

Proof: The proof is trivial from Lemma 1, 2, 3, equation (2) and inequality (5). Q.E.D.

Corollary: Managers in a delegation game invest more in R&D, produce higher output, charge lower prices and earn lower profits as compared to profit maximizers in an owner-run game.

⁸ We assume that the second-order conditions satisfy that $\eta^\alpha = \pi_i^{\alpha_i, \alpha_i} \pi_j^{\alpha_j, \alpha_j} - \pi_i^{\alpha_i, \alpha_j} \pi_j^{\alpha_j, \alpha_i} > 0$, $\pi_i^{\alpha_i, \alpha_i} < 0$ and $\pi_j^{\alpha_j, \alpha_j} < 0$, which suffices the unique existence and stability of Stage 1 equilibrium.

The intuition behind Theorem 1 and its Corollary is as follows. By lowering the managerial incentive parameter, owner i commits manager i to invest more in R&D while manager j invests less in R&D, which reduces firm i 's marginal production costs while raising firm j 's. This shifts out i 's output reaction curve while shifting in j 's. This implies a higher market share and higher profits for firm i since these two firms are in a Cournot-quantity game. Therefore, by strategically designing sales-promoting managerial incentives, an owner acts as a Stackelberg leader vs. the manager of the competing firm, and commits its manager to more aggressive actions in both the R&D and production stages, leading to higher profits. Of course in symmetric equilibrium, both owners strategically direct their managerial incentives away from profit maximization towards sales, expecting higher profits. However, the prisoner's dilemma implies higher output but lower profits for both firms than they would have had, had they chosen profit maximization as their managerial incentive.

3.2. Managerial Incentives under Cooperative R&D

In this section we allow the firms to collude in the R&D stage, but they continue to compete in the product market. The questions we would like to address are as follows. Does R&D collusion require different types of optimal managerial incentive schemes from R&D competition? How do these incentive schemes induce different R&D investment and market outcomes?

Following KMZ, R&D collusion is defined by managers coordinating their R&D activities so as to maximize their joint utility. In order to avoid cost allocation problems only the symmetric equilibrium is examined. The first-order condition in Stage 3 is given by equation (1). The managers' production decisions are the same as those in Section 3.1.

In Stage 2, manager i chooses x_i to maximize joint utility U (where $U = U_i + U_j$), yielding the first-order condition⁹

$$U^{x_i} = q_i \left(p' \frac{dq_j}{dx_i} + \alpha_i f_i' \right) + p' q_j \frac{dq_i}{dx_i} - \alpha_i = 0. \quad (6)$$

The term, $p' q_j \frac{dq_i}{dx_i}$, represents the negative externality of manager i 's R&D input on combined-utility. It is this negative externality which is ignored in equation (3) by a manager under R&D competition, but is internalized in equation (6) when managers maximizing cartel's joint utility. This negative externality inhibits managers R&D investment and results in lower R&D spending and lower output under R&D collusion than under R&D competition, as shown in KMZ. However, in strategic delegation game, as illustrated in the following equation (7), there is another effect which goes in the opposite direction through owners' choice of managerial incentives. Hence, the overall effect of R&D collusion is not as obvious as that in KMZ and the others.

Similar to Lemma 2 and 3, under cooperative R&D, the effects of managerial incentives on R&D investment and output are described by Lemma 4.

Lemma 4: Under R&D collusion, as owner i lowers α_i , firm i 's R&D investment and output increases but firm j 's decreases. That is, $\frac{dx_i}{d\alpha_i} < 0$, $\frac{dq_i}{d\alpha_i} < 0$; $\frac{dx_j}{d\alpha_i} > 0$, $\frac{dq_j}{d\alpha_i} > 0$.

Proof: See Appendix.

⁹ The unique existence and stability of a Stage 2 equilibrium requires that that $U^{x_i x_i} < 0$, $U^{x_j x_j} < 0$ and $\eta^x = U^{x_i x_i} U^{x_j x_j} - U^{x_i x_j} U^{x_j x_i} > 0$, where

$$U^{x_i x_i} = -U_i^{q_i q_i} \left(\frac{dq_i}{dx_i} \right)^2 + U_j^{q_i q_i} \frac{dq_i}{dx_i} \frac{dq_j}{dx_i} + p'' q_i \left(\frac{dq_j}{dx_i} \right)^2 + p'' q_j \left(\frac{dq_i}{dx_i} \right)^2 + p' q_i \frac{d^2 q_j}{dx_i^2} + p' q_j \frac{d^2 q_i}{dx_i^2} + \alpha_i f_i'' q_i;$$

$$U^{x_i x_j} = -U_i^{q_i q_i} \frac{dq_i}{dx_i} \frac{dq_j}{dx_j} + U_j^{q_i q_i} \frac{dq_i}{dx_i} \frac{dq_j}{dx_j} + p'' q_i \frac{dq_j}{dx_i} \frac{dq_i}{dx_j} + p'' q_j \frac{dq_i}{dx_i} \frac{dq_j}{dx_j} + p' q_i \frac{d^2 q_j}{dx_i dx_j} + p' q_j \frac{d^2 q_i}{dx_i dx_j}.$$

In Stage 1, owner i chooses α_i non-cooperatively to maximize π_i yielding the first-order conditions:

$$\pi_i^{\alpha_i} = -(1 - \alpha_i)(c - f_i) \frac{dq_i}{d\alpha_i} - (1 - \alpha_i)(1 - f_i'q_i) \frac{dx_i}{d\alpha_i} + p'q_i \left(\frac{\partial q_j}{\partial \alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right) - p'q_j \frac{dq_i}{dx_i} \frac{dx_i}{d\alpha_i}. \quad (7)$$

Note that the term, $-p'q_j \frac{dq_i}{dx_i} \frac{dx_i}{d\alpha_i}$, represents the negative externality of owner i 's choice of managerial incentive on its profit, passed from composite externality on manager i 's R&D spending and on managers combined-utility. It is this externality that is ignored in equation (4) as each manager competes in R&D stage, but internalized in equation (7) as managers maximize R&D cartel's combined utilities. This negative externality encourages each owner to lower the managerial incentive parameter and thereby commits the manager to higher R&D investment and higher output. Interestingly, this effects could be so large that it is more than offsetting the usual negative effects from forming R&D cartel, such as a decline in R&D investment and an increase in product prices.¹⁰

Rearranging the first-order condition yields

$$1 - \alpha_i = \frac{p'q_i \left(\frac{\partial q_j}{\partial \alpha_i} + \frac{dq_j}{dx_j} \frac{dx_j}{d\alpha_i} \right) - p'q_j \frac{dq_i}{dx_i} \frac{dx_i}{d\alpha_i}}{(c - f_i) \frac{dq_i}{d\alpha_i} + (1 - f_i'q_i) \frac{dx_i}{d\alpha_i}} > 0 \quad (8)$$

The symmetric equilibrium under R&D collusion is characterized by the following theorem.

¹⁰ Precise proof will be given in Theorem 4.

Theorem 2: Under R&D collusion, there exists a unique symmetric equilibrium such that $\alpha_C < 1$.

Proof: The proof is trivial from Lemma 4, equation (2) and inequality (8). Q.E.D.

In next section, we would like to compare the managerial incentives under R&D competition to that under R&D collusion and examine how these incentives in turn affect managers' R&D activities and production decisions.

4. The Comparison of Managerial Incentives under R&D Competition and R&D Collusion

For simplicity, in this section we assume that the demand function is linear, $p = a - bQ$.

The comparison between managerial incentives under R&D competition (hereafter, N) and under R&D collusion (hereafter, C) is given by Theorem 3.

Theorem 3: The managerial incentive scheme under R&D collusion is more aggressive than that under R&D competition. That is, $\alpha_C < \alpha_N$.

Proof: See Appendix.

R&D collusion, through maximizing the joint utilities, internalizes the negative externalities of managers' R&D investment on their rival managers' utilities, thereby increasing their firms' profits as compared to R&D competition. This in turn drives owners to strategically set more aggressive managerial incentives for their managers and therefore commit managers to invest more in R&D and produce more output. Letting x_C , P_C , π_C and x_N , P_N , π_N denote equilibrium R&D level, price and profits under R&D collusion and R&D competition, respectively, we have

Theorem 4: R&D collusion yields higher R&D investment, lower prices and higher profits as compared to R&D competition. That is, $x_C > x_N$, $P_C < P_N$ and $\pi_C > \pi_N$.

Proof: See Appendix.

Our results are in sharp contrast with the standard analysis in cooperative R&D as for example in KMZ. They suggest that cooperative R&D yields lower R&D investment, lower consumer surplus as compared to non-cooperative R&D, in the absence of R&D spillovers. However, this result does not necessarily hold true once owners decide managerial incentives prior to managers' R&D and production decisions. The logic behind this difference is that cooperation between managers in the R&D stage increases profitability in the product market, which induces owners to compete more in the first stage by setting more aggressive managerial incentives.¹¹ These more aggressive managerial incentives drive managers to more investment in R&D and more production in market place. As a consequence, R&D collusion yields higher R&D investment and lower prices. However, it is worth noting that firms still benefit from collusive R&D activities. Hence, in a strategic delegation game, R&D collusion unambiguously improves both consumer and producer surplus.

5. Conclusion

In this paper, we study the strategic advantages of managerial incentives in influencing firms' incentives to innovate as well as in enhancing their competitive position in market place. We conclude that for managerial firms engaging in Cournot-quantity competition,

¹¹ The intuition is similar to that contained in the semi-collusion literature. Fershtman and Gandal (1994) demonstrate that collusion in the later stage may intensify competition in the previous stage.

owners strategically design sales-promoting incentive for their managers. As a result, managers invest more, produce more, charge lower prices and make less profits as compared to the profit-maximizers. Furthermore, we elaborate the effects of collusive R&D activities on the design of managerial incentives and their consequences in product market. R&D collusion induces owners to choose more aggressive managerial incentives as compared to R&D competition. Accordingly, R&D collusion generates more R&D investment, higher production, lower product price, but higher profits. That is, cooperative R&D improves both consumer surplus and producer surplus as compared to non-cooperative R&D.

However, in this paper, we assume that there are no spillovers in firms' R&D activities.¹² Given the frequent movement of researchers and engineers and other information flow between firms, one firm's R&D activities may benefit other firms without costs. If the degree of R&D spillovers is high, owners may strategically design sales-penalizing (instead of sales-promoting) managerial incentive schemes and thereby commit managers to less aggressive behavior in both R&D activities and market place (see Zhang and Zhang (1997)).

¹² Rabah Amir (1998) provides an extensive comparison between two ways of modelling R&D with spillovers....the effect of spillover on R&D investment in Kamien-Muller-Zang (1992) model v.s. the effect of spillover on R&D final outcomes in d'Aspremont-Jacquemin (1988) model.

Appendix

Proof of Lemma 2: Implicitly differentiating Equation (3) w.r.t. α_i yields

$$\frac{dx_i}{d\alpha_i} = \frac{-\frac{\partial U_i^{x_i}}{\partial \alpha_i} U_j^{x_j x_j} + \frac{\partial U_j^{x_j}}{\partial \alpha_i} U_i^{x_i x_j}}{\eta^x} \quad \text{and} \quad \frac{dx_j}{d\alpha_i} = \frac{-\frac{\partial U_j^{x_j}}{\partial \alpha_i} U_i^{x_i x_i} + \frac{\partial U_i^{x_i}}{\partial \alpha_i} U_j^{x_j x_i}}{\eta^x}.$$

Where $\frac{\partial U_i^{x_i}}{\partial \alpha_i} = \frac{\alpha_i f'_i(c - f_i)}{\eta^q} (U_i^{q_i q_i} + \frac{2p'}{\eta^q} (U_j^{q_j q_i})^2)$, $\frac{\partial U_j^{x_j}}{\partial \alpha_i} = -2p' \frac{\alpha_j f'_j(c - f_i)}{(\eta^q)^2} U_i^{q_i q_j} U_j^{q_j q_j}$.

It is trivial that $\frac{\partial U_i^{x_i}}{\partial \alpha_i} < 0 < \frac{\partial U_j^{x_j}}{\partial \alpha_i}$ and $(\frac{\partial U_i^{x_i}}{\partial \alpha_i} + \frac{\partial U_j^{x_j}}{\partial \alpha_i}) < 0$. Hence, $\frac{dx_i}{d\alpha_i} < 0$, $\frac{dx_j}{d\alpha_i} > 0$ and $(\frac{dx_i}{d\alpha_i} + \frac{dx_j}{d\alpha_i}) < 0$ Q.E.D.

Proof of Lemma 4: Implicitly differentiating Equation (6) w.r.t. α_i yields

$$\frac{dx_i}{d\alpha_i} = \frac{-\frac{\partial U_i^{x_i}}{\partial \alpha_i} U_j^{x_j x_j} + \frac{\partial U_j^{x_j}}{\partial \alpha_i} U_i^{x_i x_j}}{\eta^x} \quad \text{and} \quad \frac{dx_j}{d\alpha_i} = \frac{-\frac{\partial U_j^{x_j}}{\partial \alpha_i} U_i^{x_i x_i} + \frac{\partial U_i^{x_i}}{\partial \alpha_i} U_j^{x_j x_i}}{\eta^x}.$$

Where $U = U_i + U_j$, and

$$\frac{\partial U_i^{x_i}}{\partial \alpha_i} = 2p' \frac{\alpha_i f'_i(c - f_i)}{(\eta^q)^2} ((U_j^{q_j q_j})^2 + (U_j^{q_j q_i})^2), \quad \frac{\partial U_j^{x_j}}{\partial \alpha_i} = -4p' \frac{\alpha_j f'_j(c - f_i)}{(\eta^q)^2} U_j^{q_j q_j} U_j^{q_j q_i}.$$

It is trivial that $\frac{\partial U_i^{x_i}}{\partial \alpha_i} < 0 < \frac{\partial U_j^{x_j}}{\partial \alpha_i}$ and $(\frac{\partial U_i^{x_i}}{\partial \alpha_i} + \frac{\partial U_j^{x_j}}{\partial \alpha_i}) < 0$. Hence, $\frac{dx_i}{d\alpha_i} < 0$, $\frac{dx_j}{d\alpha_i} > 0$.

From the the above, it is trivial that $\frac{dq_i}{d\alpha_i} < 0$, $\frac{dq_j}{d\alpha_i} > 0$. Q.E.D.

Proof of Theorem 3: For linear demand $p = a - bQ$, rearranging the first order conditions in Stage 1, 2 and 3 at the symmetric equilibrium, we have

(1) For R&D competition,

$$q = \frac{a - \alpha_N (c - f)}{3b}; \tag{a1}$$

$$f'q = \frac{3}{4}; \tag{a2}$$

$$3\alpha(1-\alpha)f'f'' + 4.5b(1-\alpha)\left(\frac{f''}{f'}\right)^2 - \alpha(f')^3 - 1.5bf'' - \frac{27b^2}{16f'}\left(\frac{f''}{f'}\right)^2 = 0. \quad (\text{a3})$$

(2) For R&D collusion,

$$q = \frac{a - \alpha_C (c - f)}{3b}; \quad (\text{a4})$$

$$f'q = \frac{3}{2}; \quad (\text{a5})$$

$$3\alpha(1-\alpha)f'f'' + 4.5b(1-\alpha)\left(\frac{f''}{f'}\right)^2 + 1.5\alpha(f')^3 + 0.75(5+3\alpha)bf'' - \frac{27b^2}{8f'}\left(\frac{f''}{f'}\right)^2 = 0. \quad (\text{a6})$$

$$\text{Denote } N(\alpha) = 3\alpha(1-\alpha)f'f'' + 4.5b(1-\alpha)\left(\frac{f''}{f'}\right)^2 - \alpha(f')^3 - 1.5bf'' - \frac{27b^2}{16f'}\left(\frac{f''}{f'}\right)^2,$$

$$C(\alpha) = 3\alpha(1-\alpha)f'f'' + 4.5b(1-\alpha)\left(\frac{f''}{f'}\right)^2 + 1.5\alpha(f')^3 + 0.75(5+3\alpha)bf'' - \frac{27b^2}{8f'}\left(\frac{f''}{f'}\right)^2.$$

Then α_N is the solution to $N(\alpha) = 0$ and α_C is the solution to $C(\alpha) = 0$.

Since $N(\alpha) = C(\alpha) - 2.5\alpha(f')^3 - 0.75(7+3\alpha)bf'' + \frac{27b^2}{16f'}\left(\frac{f''}{f'}\right)^2 > 0$, moreover from the second order condition $\pi^{\alpha\alpha} < 0$, we have $N'(\alpha) < 0$. Thus, $\alpha_N > \alpha_C$ Q.E.D.

Proof of Theorem 4: From (a1) and (a2), (a4) and (a5), we know that x_N and x_C are the solutions to $f'(a - \alpha_N (c - f)) = \frac{9b}{4}$ and $f'(a - \alpha_C (c - f)) = \frac{9b}{2}$, respectively.

$$\text{Denote } N(x) = f'(a - \alpha_N (c - f)) - \frac{9b}{4} \text{ and } C(x) = f'(a - \alpha_C (c - f)) - \frac{9b}{2}.$$

Since $N(x) = C(x) - (\alpha_N - \alpha_C)(c - f)f' + 2.25b < 0$ and $N'(x) < 0$. Thus, $x_C > x_N$.

From (a1) and (a4), it is trivial that $q_C > q_N$.

Now we want to show that $\pi_C > \pi_N$.

$$\pi_C(\alpha_C) > \pi_C(\alpha_N) = \frac{(a - \alpha_N (c - f(x_{CN}))) (a - (3 - 2\alpha_N) (c - f(x_{CN})))}{9b} - x_{CN}, \text{ where}$$

$$x_{CN} \text{ is the solution to } f'(a - \alpha_N (c - f)) = \frac{9b}{2}.$$

Since x_N is the solution to $f'(a - \alpha_N (c - f)) = \frac{9b}{4}$. Thus, $x_{CN} < x_N$.

Moreover, since $\frac{d}{dx_{CN}}[(a - \alpha_N(c - f(x_{CN}))) (a - (3 - 2\alpha_N)(c - f(x_{CN}))) - 9bx_{CN}]$

$$= f'[(3 - \alpha_N)(a - \alpha_N(c - f(x_{CN}))) - 3\alpha_N(1 - \alpha_N)(c - f(x_{CN}))] - 9b$$

$$= 3(1 - \alpha_N)[1.5b - \alpha_N(c - f(x_{CN}))f'] < 0$$

Therefore, $\pi_C(\alpha_N) = \frac{(a - \alpha_N(c - f(x_{CN}))) (a - (3 - 2\alpha_N)(c - f(x_{CN})))}{9b} - x_{CN}$

$$> \frac{(a - \alpha_N(c - f(x_N))) (a - (3 - 2\alpha_N)(c - f(x_N)))}{9b} - x_N = \pi_N(\alpha_N).$$

That is, $\pi_C > \pi_N$. Q.E.D.

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